PROVIDING CLINICIANS WITH PROBLEM-BASED ACCESS TO KNOWLEDGE: TROUBLESHOOTING PULMONARY ARTERY CATHETER WAVEFORMS

R.D. Zielstorff, RN, MS; G.O. Barnett, MD; J.B. Fitzmaurice, RN, PhD; D.E. Oliver, MD; P. Ford-Carleton, RN, MS; B.T. Thompson, MD; G. Estey, EdM; R. Eccles, BS; M. Martin, RN, BS; R. Jenders, MD

Massachusetts General Hospital, Boston MA 02114

This paper describes a microcomputer system for providing computer-based access to expert knowledge in the area of troubleshooting pulmonary artery (PA) catheter waveforms. The system is used by both nurses and physicians in an 18-bed medical intensive care unit. Its dominant features are 1) problem-focused access to knowledge, and 2) heavy use of graphics and images to explicate knowledge. The system is used by both nurses and physicians in an 18-bed medical intensive care unit. An evaluation protocol is in place to examine the impact of the system on clinicians' knowledge, their decision-making skills, their satisfaction with the system, and costs of orientation related to PA waveform troubleshooting.

INTRODUCTION

There are several barriers to effective clinical decision-making that are theoretically amenable to technological intervention. Among the most important of these barriers are inadequate access to information or knowledge and inadequate expertise in applying available knowledge to the case at hand.

Technologies have been developed to provide clinicians with access to knowledge, but each has its limitations. NLM's MEDLINE is a boon to researchers, to academics and to students, but when clinicians need answers to questions about specific patients, bibliographic retrieval is less frequently exploited. Many clinicians have difficulty formulating searches that will answer a patient-specific question [1]; and even when relevant articles are found, they have difficulty evaluating the quality of the material [2,3]. Furthermore, because knowledge in the health sciences is generally accumulated as a result of many small-scale studies, any one article, unless it is a comprehensive review, is unlikely to provide a definitive answer.

Another approach is to provide access to knowledge via knowledge management systems. However, ambiguities and disorientation may be experienced by the naive user in trying to find an answer to a specific, limited clinical question. Most sytems are not organized in a way that takes into account clinicians' difficulty with formulating general queries to answer patient-specific questions, and their difficulty evaluating existing material. The amount of time that is required to navigate through the various knowledge bases and to correlate and synthesize the facts gained in order to answer a patient-related question are impediments to use of these systems. What is needed is easy access to *synthesized* knowledge that is presented in the context of *specific patient problems*.

One technological solution to supporting decision-making for clinicians has been the development of expert systems. Major research efforts have resulted in systems such as MYCIN [4], ONCOCIN [5], QMR [6], DXplain [7], CANDI [8], FLORENCE [9], and others [10,11,12].

While these are important contributions to clinical decision-making, they have limitations in providing clinical decision support except in the area of differential diagnosis or for a few very specific management issues. Many such systems have only limited ability to teach and to present rationales for their recommendations. They often require extensive interaction with the user in order to gather all the facts needed to provide their recommendations. They are generally not available at the point of care, where the need to know is greatest. Also, the laborious process of extracting from experts their knowledge and models of decision making, communicating this to knowledge engineers, and translating it into computer code is a major impediment to more widespread development of these systems [13].

0195-4210/92/$5.00

It appears that for clinicians (as is true for most students and adult learners), the most effective form of learning occurs in the process of solving diagnostic and management problems in the context of a specific case [14]. Not only is the "need to know" a prime motivation in query and consultation, but separate studies indicate that learning in a clinical, case-oriented context leads to increased retention and expertise in applying knowledge [15,16,17].

PROBLEM-BASED KNOWLEDGE ACCESS

The system we developed presents synthesized knowledge of domain experts in the context of case-specific patient problems selected by the clinician. It incorporates not only the empirical knowledge found in the accumulation of research about the specific problem, but also an expert's clinical knowledge that is gained only through experience. Instead of requiring the content experts to dissect their knowledge into discrete facts and complex associations, their knowledge is formalized in terms of "chunks" of specific, relevant information that is associated with a particular clinical context. Presenting knowledge in this way provides clinicians with easy access to expert knowledge that can be used both for case-specific consulation and for case-oriented education.

Significance of the Clinical Topic

The pulmonary artery catheter has come into widespread clinical use during the past twenty years. However, use of the pulmonary artery catheter is not risk-free. Complications can occur, and the data may be misleading if appropriate attention is not given regarding technique and management of the pulmonary catheter [18]. Evaluating whether a catheter is functioning properly and, if a problem is detected, finding and fixing the problem, becomes a basic requirement in the appropriate use of this invasive technique. Yet knowledge about use and management of PA catheters among clinicians is variable [19]. Programs that teach the specifics of troubleshooting the placement of the catheter and the interpretation of the waveform, especially for physicians, vary from superficial to nonexistent.

Another reason to select this topic is that it lends itself to a repertoire of indexing techniques: contextual, graphical, and problem-based. The experience we gained in developing and implementing this topic area will be highly useful for developing a richer application in the next two funded areas: prevention and management of pressure ulcers, and management of patients on ventilators.

System Design

The knowledge base of the PA Catheter Waveform Troubleshooting System is organized hierarchically, first by waveform category (Right Atrium, Pulmonary Artery, or Pulmonary Capillary Wedge), then by specific types of waveform abnormalities (damping, respiratory variation, etc.) represented graphically on the screen. Having selected a waveform that looks similar to the problem, the clinician is then brought into the knowledge base. Knowledge about each waveform is "chunked" according to Characteristics, Causes, Management, and obtaining the best Measurement. Graphics, images and animation are used extensively to convey the knowledge in the most effective way. Within the text, terms that might need definition or further explication are designated as selectable "hot words."

A consistent set of icons allows the user to navigate within the knowledge base. Some buttons allow the user to leave the waveform-specific knowledge and go into the glossary or into the tutorial section of the knowledge base. Other buttons allow the user to go back to the set of waveform choices, or to the waveform categories, or to exit the system entirely. Figure 1 shows a representative screen in the waveform knowledge base.

The system runs under Microsoft Windows 3.0 or 3.1 on computers based on the Intel 80386 or 80486 microprocessors with 8 megabytes or more of memory and SuperVGA displays with resolution of 1024 x 768 and 256 colors. For reasons of performance, all systems installed on the intensive care units have been 80486-based computers with 16 megabytes of memory. Most programming for the system was done using Toolbook, a popular hypertext authoring environment; some additional programming was done in C. Graphics used in the system came from several sources: many of the waveforms used in the system originated in the Massachusetts General Hospital /Marquette Foundation Database developed by other researchers at our institution; most of the illustrations in the system were drawn for use in the system using CorelDRAW or Micrografx Designer.

The final design of the system evolved from several years' investigation of hypertext methods of knowledge construction and presentation [20,21]. It was out of that experience, as well as out of an iterative process which included a formative evaluation and a three-month beta test in a surgical

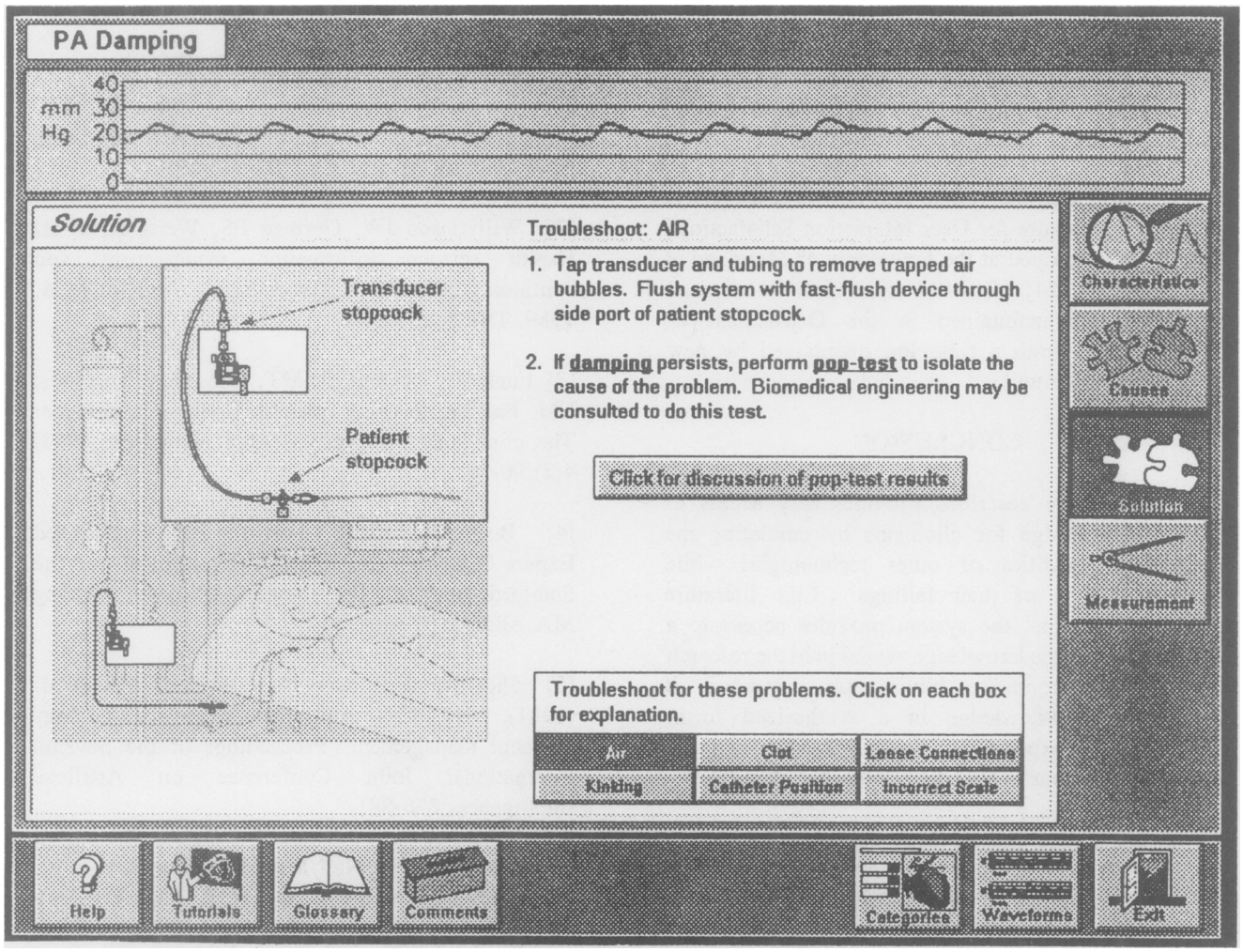

Figure 1. Representative screen from Waveform knowledge base

intensive care unit, that the current design evolved. In essence, the most pervasive lessons have been: a) the indexing methods must be problem-focused; b) the knowledge constructs must be clinically meaningful; c) navigation within the system must be straightforward, maintaining consistent contextual cues; and d) the text explanations must be terse [12].

Implementation of the System

The system has been implemented on an 18-bed medical intensive care unit, where there are approximately 3-5 PA lines in place at any one time. After three months, of 50 staff nurses, 37 have registered to use the system, and 26 have used it. House officers rotate through the unit monthly. Of 24 house officers who have rotated through thus far, 16 have registered, and 9 have used the system. As of this writing, the system has been used approximately 170 times for patient care, for educational browsing, and for training or orientation.

Evaluation of the System

An evaluation protocol has been designed to examine the impact of the system on clinicians' knowledge, their decision-making skills, their satisfaction with the system, and costs of orientation related to PA waveform troubleshooting. The evaluation protocol is being carried out on the experimental unit and also on a comparison medical intensive care unit whose personnel do not have access to the system.

Clinicians' knowledge is assessed via a multiple-choice test developed for this project. The test is administered prior to each person's use of the system, and after using it. Nurses' decision-making skills are

assessed via case simulations developed for this project, administered before and after use of the system. The instructional adequacy of the system is being assessed using a tool developed for evaluating computer-based instruction systems [23].

Satisfaction with the system interface is assessed via the "Questionnaire for User Interaction Satisfaction" (QUIS™) developed at the University of Maryland at College Park [24]. Costs of orientation are assessed from figures maintained in the Department of Nursing and from a time log maintained by new orientees to the unit.

CONCLUSION

The system we described provides easy access to expert knowledge for clinicians by emulating the successful qualities of other technologies while avoiding some of their failings. Like literature retrieval systems, the system provides access to a selected set of the knowledge available in the research literature; but unlike bibliographic systems, it presents the knowledge in a synthesized form, evaluated by experts, and organized into segments that are pertinent to specific clinical problems.

Like knowledge management systems, the system provides access to knowledge resources in diverse media (text, graphics, videodisk images); but it does so using indexing methods based on clinical problems and the critical findings associated with them. Finally, like expert systems, the system makes use of particular patient findings to focus the presentation of information by the system; but unlike such systems, it uses a combination of indexing methods that allow the user, rather than the system, to control the interaction.

An evaluation protocol is in place to see whether using the system has positive effects on clinicians' knowledge and clinical decision-making skills, on their satisfaction with use of the system, and on costs of orienting them to PA catheter waveform troubleshooting. Experience with this topic will be applied to the design of similar systems to provide expert knowledge in the areas of prevention and management of pressure ulcers and management of patients on ventilators.

REFERENCES

[1] Covell DG, Uman GC, Manning PR. Information needs in office practice: Are they being met? Ann Int Med, 1985, 103:596-599.

[2] Williamson JW, German PS, Weiss R, et al. Health science information management and continuing education of physicians. Ann Int Med, 1989, 110(2):151-160.

[3] Funk SG, Champagne MT, Wiese RA, Tornquist EM. Barriers to using research findings in practice: The clinician's perspective. Appl Nurs Res, 1991, 4(2):90-95.

[4] Buchanan BG & Shortliffe EH. Rule-Based Expert Systems: The MYCIN Experiments of the Stanford Heuristic Programming Project. Reading MA:Addison Wesley, 1984.

[5] Shortliffe EH, Scott AC, Bischoff MB et al. (1981). ONCOCIN: An expert system for oncology protocol management. Proceedings of the Seventh International Joint Conference on Artificial Intelligence, 876-881.

[6] Miller RA, McNeil MA, Challinor SM, et al. The INTERNIST-1/QUICK MEDICAL REFERENCE Project - Status Report, West J Med, 1986, 145:816-822.

[7] Barnett GO, Cimino JJ, Hupp JA, Hoffer EP. DXplain - An evolving diagnostic decision-support system. JAMA, 1987, 258:67-74.

[8] Chang BL, Roth K, Gonzales E, Caswell D and DiStefano J. CANDI: A knowledge-based system for nursing diagnosis. Comput Nurs 1988, 6(1):13-21.

[9] Bradburn C, Zeleznikow J and Adams A. FLORENCE: Synthesis of case-based and model-based reasoning in a nursing care planning system. Comput Nurs 1993, 11(1):20-24.

[10] Heriot C, Graves J, Bouhaddou O, et al. A pain management decision support system for nurses. In: RA Greenes (ed). Proceedings of the Twelfth Annual Symposium on Computer Applications in Medical Care. New York: IEEE Computer Society Press, 1988:63-68.

[11] Blaufuss JA and Tinker AK. Computerized falls alert: A new solution to an old problem. In: RA Greenes (ed). Proceedings of the Twelfth Annual Symposium on Computer Applications in Medical Care. New York: IEEE Computer Society Press,B 1988:69-72.

[12] Ryan SA. An expert system for nursing practice. Comput Nurs, 1985, 3(2):77-84.

[13] Musen, MA & van der Lei, J. Knowledge engineering for clinical consultation programs: modeling the application area. Meth Inform Med, 1989, 28:28-35.

[14] Covell et al, op cit.

[15] Norman GR. The role of knowledge in teaching and assessment of problem-solving. J Instruct Devel, 1985, 8(1):7-11.

[16] Corcoran SA & Tanner C. Implications of clinical judgment research for teaching. In: Curriculum Revolution: Mandate for Change. New York: National League for Nursing. NLN Pub No. 15-2224, 1988:159-176.

[17] Coughlin LD & Patel VL. Processing of critical information by physicians and medical students. J Med Educ, 1987, 62:818-828.

[18] Civetta JM. Pulmonary Artery Catheter Insertion. In: CL Sprung (ed). The Pulmonary Artery Catheter, Methodology and Clinical Applications. Baltimore: University Park Press, 1983:21-71.

[19] Iberti TJ, Fischer EP, Leibowitz AB, et al. A Multicenter Study of Physicians Knowledge of the Pulmonary Artery Catheter. JAMA 264(22):2928-2932.

[20] Estey G, Oliver DE, Chueh HC, et al. Problem-based knowledge access: useful design principles for clinical hypertexts. In: RA Miller (ed). Proceedings of the Fourteenth Annual Symposium on Computer Applications in Medical Care. New York: IEEE Press, 1990:430-434

[21] Oliver DE, Estey G, Ford P. Computer-based access to patient care guidelines. In: RA Miller (ed). Proceedings of the Fourteenth Annual Symposium on Computer Applications in Medical Care. New York: IEEE Press, 1990:398-402.

[22] Estey et al, op cit.

[23] Underwood SM. Measuring the validity of computer-assisted instructional media. In: OL Strickland & CF Waltz (eds). Measurement of Nursing Outcomes. Vol 2. New York: Springer Publishing, 1988:294-313.

[24] Chin JP, Diehl VA, Norman KL. Development of an instrument measuring user satisfaction of the human-computer interface. In: CHI'88 Conference Proceedings: Human Factors in Computing Systems. New York: Association for Computing Machinery, 1988:213-218.

==========

Funded by Grant 5 R18 HS06575, Agency for Health Care Policy and Research, PHS, USDHHS; and by Grant 1 T15 LM07092 and Grant 5 R01 LM05200, National Library of Medicine, NIH, PHS, USDHHS; and by an educational grant from Hewlett Packard corporation.